MAKING MEASUREMENTS

TIME

The times that are required to work out the problems can easily be measured by using a watch with a second hand or a digital watch with a stop watch mode. When measuring the period of a ride that involves harmonic or circular motion, measure the time for several repetitions of the motion. This will give a better estimate of the period of motion than just measuring one repetition. You may want to make two or three measurements of the time, and then average your results.

DISTANCE

Since you cannot interfere with the normal operation of the rides, you will not be able to directly measure heights, diameters, etc. All but a few of the distances can be measured remotely using the following methods. They will give you a reasonable estimate. Try to keep consistent units, e.g. meters, centimeters, etc., to make calculations easier.

Pacing: Determine the length of your stride by walking at your normal rate over a measured distance. Divide the distance by the number of steps and you can get the average distance per step. Knowing this, you can pace off horizontal distances.

My pace = __________ m

Ride Structure: Distance estimates can be obtained by making use of regularities in the structure of the ride. For example, tracks may have regularly spaced cross-members as shown in ***figure a.*** The distance **d** can be estimated, and by counting the number of cross members, distances along the track can be determined. This method can be used for both vertical and horizontal distances.

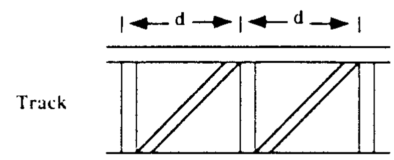


Figure a

Triangulation: For measuring height by triangulation, an astrolabe such as that shown in ***figure b*** can be used (see next page).

Practice this with the school flagpole before you come to the park.

Suppose the heights $\mathbf{h_T}$ of the **roller coaster** must be determined.

1. Measure the distance between you and the ride. You can pace off the distance.

   distance **d**: __________ m

2. Measure the height of the sighting tube.

   sighting tube height $\mathbf{h_2}$: $\mathbf{h_2}$=__________ m

3. Take a sighting at the highest point of the ride.

4. Read off the angle of elevation.

angle of elevation __________ °

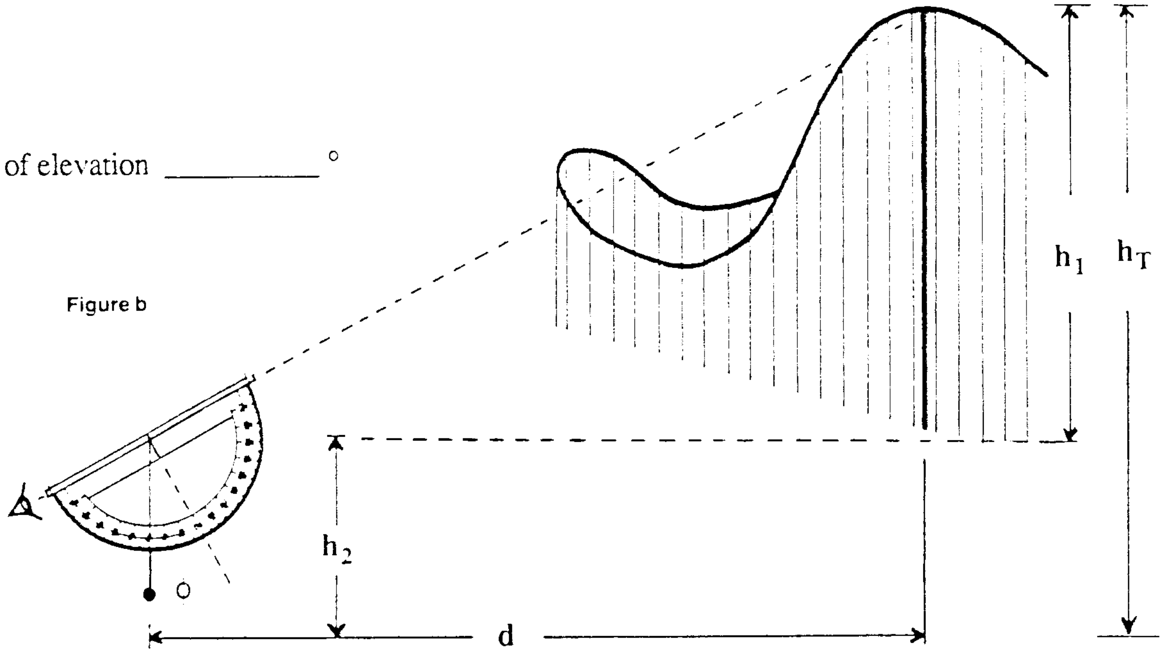


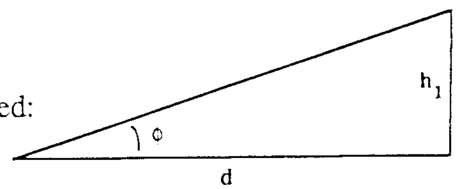
Figure b

Then since

$$h_1/d = \tan \phi$$

$$h_1 = d(\tan \phi)$$

5. Look up the tangent value for the angle measured:



tangent value: __________

Angle	Tangent	Angle	Tangent	Angle	Tangent
0°	0.00	35°	0.70	70°	2.75
5°	0.09	40°	0.84	75°	3.73
10°	0.18	45°	1.00	80°	5.67
15°	0.27	50°	1.19	85°	11.43
20°	0.36	55°	1.43	90°	∞
25°	0.47	60°	1.73		
30°	0.58	65°	2.14		

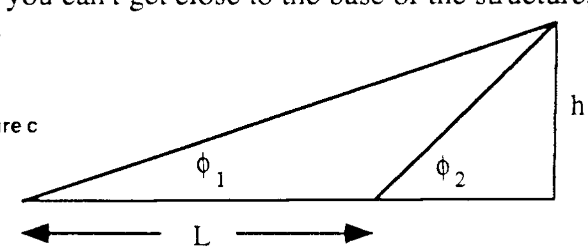
6. Multiply this tangent value by the distance from the ride: h_1 = __________ m

7. Add this product to the height of the sighting tube: h_2 = __________ m

This number is the height of the ride. h_T = __________ m

Other: There are other ways to measure distance. If you can think of one, use it. For example, a similar but more complex triangulation could be used. If you can't measure the distance **L** because you can't get close to the base of the structure, use the Law of Sines as in ***figure c*** below.

Figure c



Knowing ϕ_1, ϕ_2, and L, the height h can be calculated using the expression: $h = \left[\frac{\sin\phi_1 \cdot \sin\phi_2}{\sin(\phi_2 - \phi_1)}\right] \cdot L$

SPEED

In linear motion, the average speed of an object is given by:

$$v_{ave} = \frac{\Delta d}{\Delta t}$$

In circular motion, where speed of rotation is constant:

$$v_{ave} = \frac{\Delta d}{\Delta t} = \frac{2\pi r}{\Delta d}$$

Both these cases involve fairly constant speed. Be careful of measuring speed when the speed is changing. If you want to determine the speed at a particular point on the track, measure the time that it takes for the length of the train to pass that particular point. The train's speed then is given by:

$$v_{ave} = \frac{\Delta d}{\Delta t} = \frac{\text{length of train}}{\text{time to pass point}}$$

In a situation where it can be assumed that total mechanical energy is conserved, the speed of an object can be calculated using energy considerations. Suppose the speed at point **C** is to be determined (see ***figure d***). From the principle of conservation of total mechanical energy it follows that:

$$PE_A + KE_A = PE_C + KE_C$$

$$mgh_A + 1/2mv_A^2 = mgh_C + 1/2mv_C^2$$

Since mass is constant, solving for v_C:

$$v_C = \sqrt{2g(h_A - h_C) + v_A^2}$$

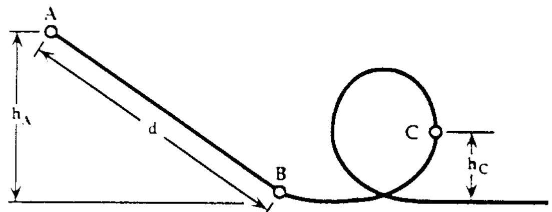
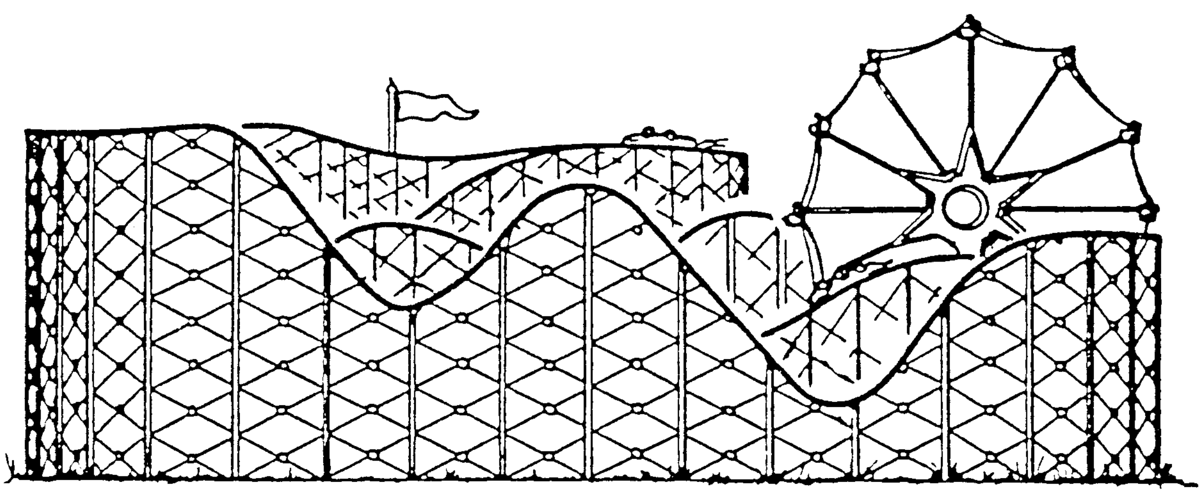


Figure d

Thus by measuring the speed of the train at point **A**, and the heights h_A and h_C, the speed of the train at point **C** can be calculated.



ACCELERATION

Accelerometers are designed to record the **g** forces felt by a passenger. Accelerometers are usually oriented to provide force data perpendicular to the track, longitudinally along the track, or laterally to the right or left of the track (see ***figure e***).

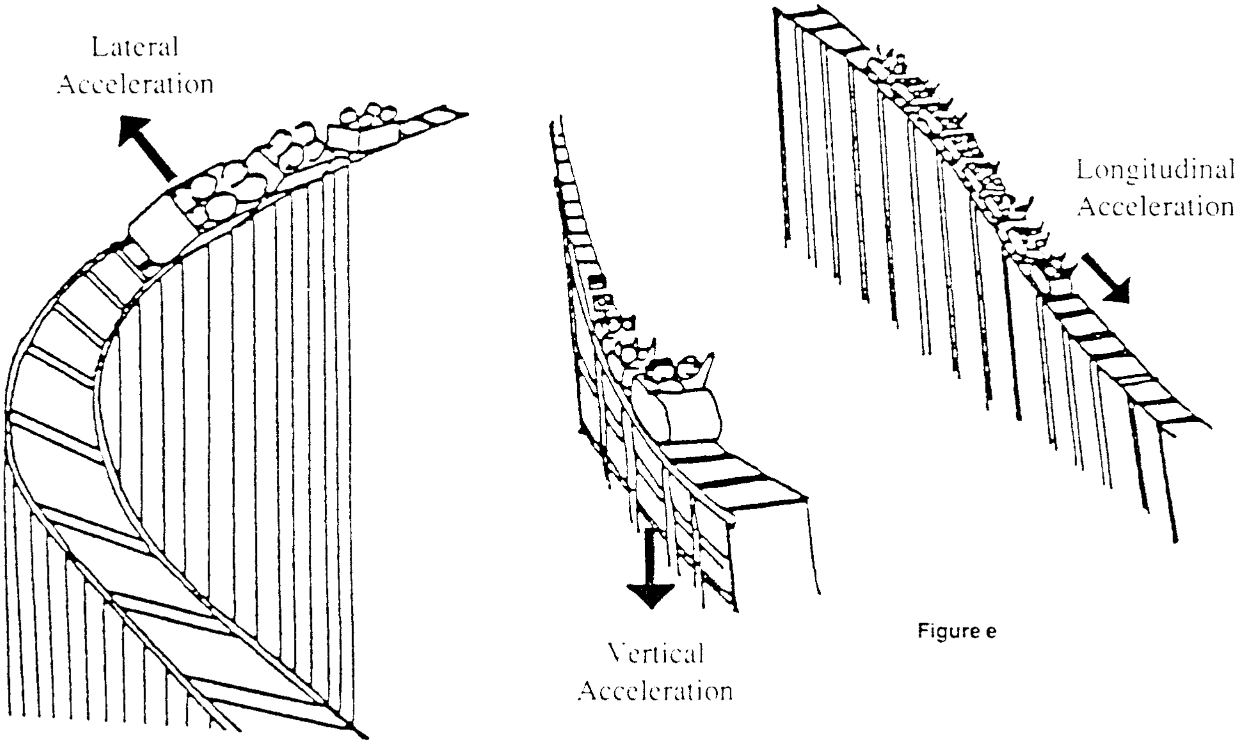


Figure e

Accelerometers are calibrated in g's. A reading of 1 g equals an acceleration of 9.8 m/s^2. As you live on earth, you normally experience 1 g of acceleration vertically (no g's laterally or longitudinally). Listed below are the sensations of various 'g forces'. These are rough estimates, but may be helpful in estimating accelerations on the various rides.

Accelerometer Reading	Sensation
3 g	3 times heavier than normal (maximum g's pulled by space shuttle astronauts)
2 g	twice normal weight
1 g	normal weight
0.5 g	half-normal weight
0 g	weightlessness (no force between rider and coaster)
-0.5 g	half-normal weight -- but directed upward away from coaster seat (weight measured on bathroom scale mounted at rider's head!)

LATERAL ACCELERATION

The Astrolabe as Accelerometer

The astrolabe discussed earlier as a triangulation instrument may also be used to measure lateral accelerations. The device is held with the sighting tube horizontal, and the weights swing to one side as you round a curve. From the angle by which they deviate from the center, the acceleration can be determined. See the drawing below ***(figure f)***, which shows how lead balls in a semicircular tube deviate when the tube is carried round a corner:

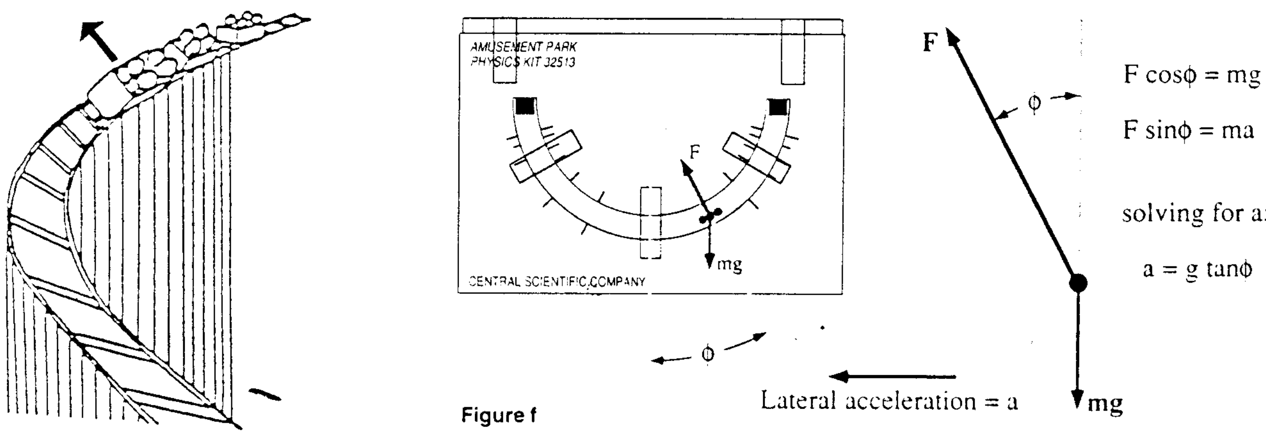


Figure f

NOTE that the weights deviate in the direction OPPOSITE to that of the acceleration vector!

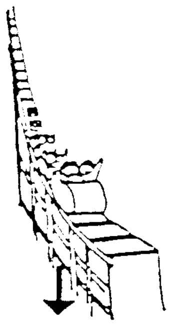
Centripetal Acceleration: With uniform circular motion remember that: $v = \dfrac{2\pi r}{t}$

and the centripetal acceleration is given by: $a_c = \dfrac{v^2}{r} = \dfrac{4\pi^2 r}{t^2}$

where **r** is the radius of the circle and **t** is the period of rotation.

Thus centripetal acceleration can be measured on a ride.

VERTICAL ACCELERATION



A simple device for measuring vertical accelerations is a 0-5 Newton spring scale with a 100 g mass attached. The plastic tubes with springs and fishing weights approximate this equipment. The forces on the mass are as drawn where F_T is the reading on the scale.

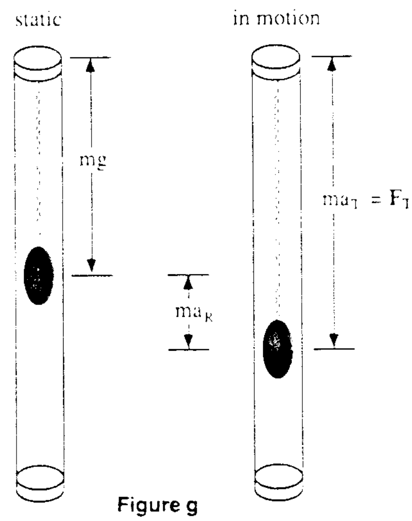


Figure g

The forces on the masses are shown in the diagram. *(figure g).*

If the person is holding the scale right side up, then:

$F_T = mg + ma_{(Ride)}$ or $ma_{(Total)} = mg + ma_{(Ride)}$

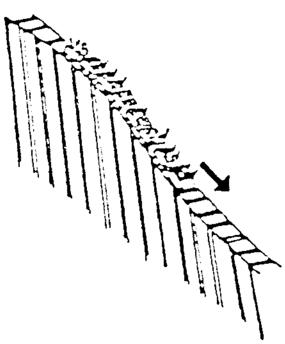
since m is constant,

$a_T = g + a_R$ or $a_R = a_T - g$

If the person is holding the scale upside down against gravity as might be found at the top of a giant looper, then

$a_R = -(a_T + g)$ i.e. acceleration is upwards

In either situation, then, the acceleration can be calculated by knowing F_T(or a_T).



LONGITUDINAL ACCELERATION

Acceleration of a person on a ride can also be determined by direct calculation. Down an incline, the average acceleration of an object is defined as:

$$a_{ave} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\text{change in speed}}{\text{change in time}}$$

Using methods previously discussed it is possible to estimate speeds at both the top and bottom of the hill and the time it takes for the coaster to make the trip. Thus average acceleration can be found during that portion of the ride.

The Great Bear-Vertical Acceleration